MEMS Segmented DM Development in Support of Exoplanet Missions

Iris AO, Inc.

Dr. Michael Helmbrecht, Min He, Dr. Carl Kempf, Patrick Rhodes

NNG07CA06C Phase II SBIR Technology Advances

Jan 2007 – May 2009

30 X Increase in DM Positioning Resolution

- Prior to SBIR: 14.8 nm *rms* on 5 µm-stroke DM
  - Limited by electronics noise
- After SBIR: 0.5 nm *rms (*1.8 nm LSB), on 6µm-stroke DM
  - Limited by 14-bit drive electronics resolution and DM stroke

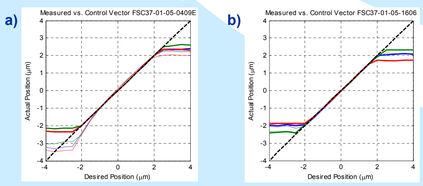
Electronics Development

- Low noise, 14-bit drive electronics developed and commercialized
  - Units sold within 10 months of starting Phase II research
- > 10X reduction in broadband noise compared to 1st generation drive electronics
- > 30X reduction in band-limited noise (< 2kHz)
  - Noise floor below 14-bit resolution

DM Design Modified

- Design modified to use more of the electronics dynamic range
- Prior to SBIR, 5 µm stroke DMs operated with ~60V
- After SBIR, 6 µm-stroke DMs operate with 120V

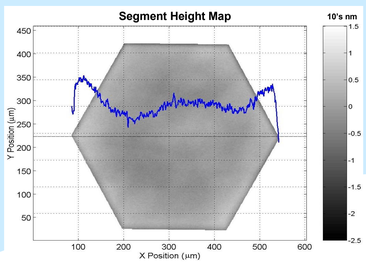
Improved Open-Loop Control



a) Experimental data showing open-loop controller performance of the controller prior to the SBIR funded research, and b) improvements made to the controller in later stages of the grant. Data are shown for three DM segments. The dashed line shows the commanded positions. The thick colored lines show the positions the controller commands the mirrors to go to. The thin lines are the actual positions the DM segments go to.

Improved DM Flatness

- Prior to SBIR: Segment flatness varies 6-20 nm *rms* across DM and from DM to DM
  - Segments w/ ~2nm *rms* have been demonstrated
- After SBIR: Goal of 1-3 nm *rms* across DM and from DM to DM
  - Tests will be complete May 2009

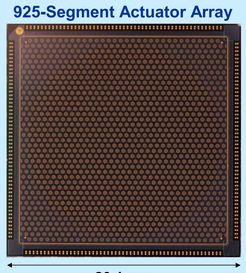


Segment Flatness – 2.13 nm *rms*

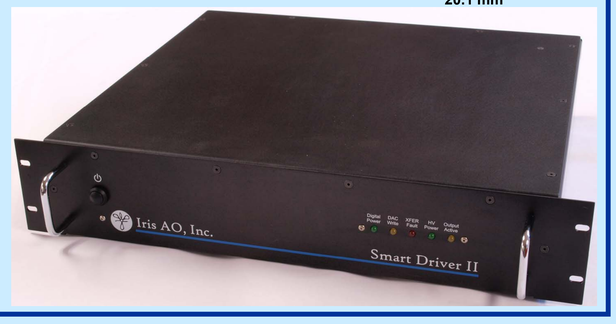
DM Scaling

- Prior to SBIR
  - 37 segment DM
  - 128-channel drive electronics
- After SBIR:
  - 2 process runs of 925-segment demonstration actuator array w/ ganged electrodes
  - 128 & 512-channel drive electronics
    - USB interfaced electronics can be daisy chained to run >10k channels

925-Segment Actuator Array



20.1 mm

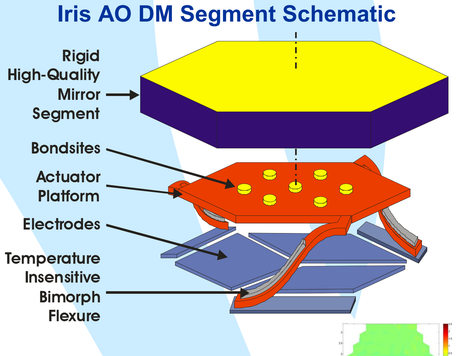


Iris AO Product Line

S37-X: Easiest to Use DM on the Market

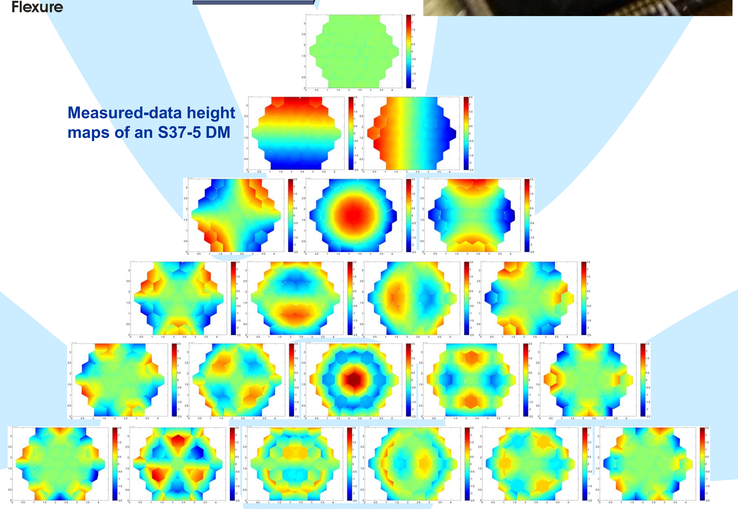
- Intuitive interface: User specifies mirror position instead of voltages
  - Positions specified as segment PTT values or Zernike coefficients for entire DM
- Factory calibrated piston/tip/tilt controller enables excellent open loop positioning
  - Mirror position is linear and accurate
- No coupling between segments and excellent open loop control simplify closed-loop control and improve closed-loop performance
  - No wasted control-loop samples to iterate to best correction means higher correction bandwidth
- Unique hybrid design enables use of thick, high optical quality segments

Iris AO DM Segment Schematic



S37-X DM Die Photo

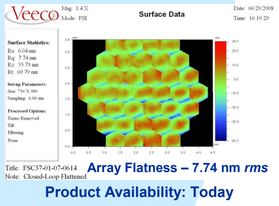
Measured-data height maps of an S37-5 DM



Measured data of open-loop DM operation:
37 piston/tip/tilt commands entered into controller
DMs overdriven to demonstrate position limiting

DM Roadmap

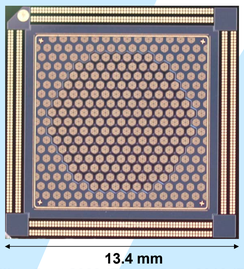
S37-X, 111 actuator, 37 segment DM
700 µm segment, 3.5 mm aperture



Array Flatness – 7.74 nm *rms*

Product Availability: Today

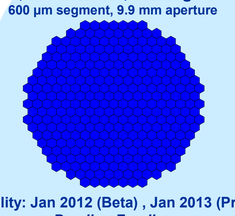
S163-X, 489 actuator, 163 segment DM
700 µm segment, 7.7 mm aperture



13.4 mm

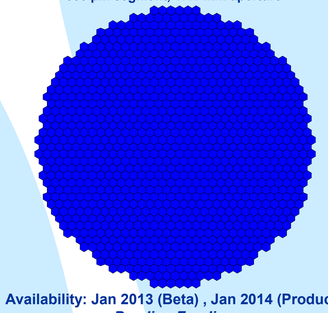
Availability: Sept 2009 (Beta) , Sept 2010 (Product)

S313-X, 939 actuator, 313 segment DM
600 µm segment, 9.9 mm aperture



Availability: Jan 2012 (Beta) , Jan 2013 (Product)
Pending Funding

S1015-X, 3045 actuator, 1015 segment DM
600 µm segment, 17.1 mm aperture



Availability: Jan 2013 (Beta) , Jan 2014 (Product)
Pending Funding

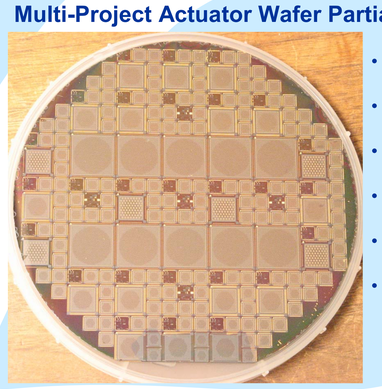
NNX09CE01P Phase I SBIR and Proposed Phase II SBIR Technology Objectives

Jan-July 2009

Phase I Objectives

- Further develop MEMS fabrication processes for large DM arrays
- Demonstrate ability to wire to 3000+ actuators on MEMS chip
- Quantify yield reducers
- Propose process improvements
- Demonstrate assembly and operation of 925-segment array
  - Array has ganged electrodes

Multi-Project Actuator Wafer Partially Funded by Phase I Research



- 37, 163, and 925 segment actuator arrays built on same wafer
- 37 and 163 segment designs are complete
- 925-segment demonstration design with ganged electrodes
- Costs spread across multiple projects for early development
- Wafer shown has mechanical layers only
- Wafer with electrodes and wiring currently being fabricated

Proposed Phase II Objectives (proposal to be submitted July 2009)

- *Hardware Deliverable:* Fully wired S331-X DM
  - Lower stroke to increase resolution
  - Reduced electrode sizing to use full dynamic range of electronics and increase resolution
- Improve fabrication process to increase segment yield
- Design and fabricate fully wired S1013-X DM
  - Packaging beyond the scope of a single Phase II SBIR
    - Funding source TBD

Additional Development at Iris AO

- High-speed (5 kHz) electronics interface
- Protected-silver coatings
- Dielectric coatings
  - Mirror segments fabricated with stress compensation layer to counteract stresses from thick (1-3 µm) dielectric coatings
- Environmental testing

SBIR Commercialization Path

Most of the DM and electronics technologies developed under NASA SBIR NNG07CA06C have been instrumental in developing the S37-X DM. The Phase I research currently underway (NNX09CE01P) and the Phase II research to be proposed will expand the Iris AO product line by supporting process development critical to the S163-X and by developing the S331-X DM. Revenues from these products will be reinvested into IR&D to continue the development of high-performance DMs.

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www.irisao.com michael.helmbrecht@irisao.com 510-849-2375